

# NSIs in Semileptonic Rare Decays of Mesons Induced by Second Generation of Quarks ( $c$ -quark and $s$ -quark)

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## Abstract

We study rare decays  $D_s^+ \rightarrow D^+ \nu \bar{\nu}$ ,  $B_s^0 \rightarrow B^0 \nu \bar{\nu}$  and  $K^+ \rightarrow \pi^+ \bar{\nu} \nu$  in the frame work of NSIs. We calculate Branching ratios of these decays. We explore the possibility for second generation of quarks in NSIs just like leptonic contribution in  $\epsilon_{\alpha\beta}^e, \epsilon_{\alpha\beta}^\mu$  and  $\epsilon_{\alpha\beta}^\tau$ . We study the dependence of  $B_s^0 \rightarrow B^0 \nu \bar{\nu}$  on  $\epsilon_{\tau\tau}^{uL}$ . We show that there exist a possibility for  $\epsilon_{\tau\tau}^{cL}$ , also from these reactions. Three other processes  $D^+ \rightarrow \pi^+ \bar{\nu} \nu$ ,  $D^0 \rightarrow \pi^0 \bar{\nu} \nu$  and  $D_s^+ \rightarrow K^+ \bar{\nu} \nu$  are investigated with  $s$  quark in the loop for NSIs instead of  $d$  quark. Constraints on  $\epsilon_{\tau\tau}^{sL}$  and  $\epsilon_{ll'}^{sL}$  ( $l, l' \neq \tau$ ) are provided. We point out that constraints for both  $u$  and  $c$  quark are equal ( $\epsilon_{\tau\tau}^{uL} = \epsilon_{\tau\tau}^{cL}$ ) and similarly for  $d$  and  $s$  quarks the constraints are equal ( $\epsilon_{\tau\tau}^{dL} = \epsilon_{\tau\tau}^{sL}$ ).

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## 1 Introduction

Rare decays of mesons having two neutrinos in the final state are thought to be a clean signal for the NP. These decays provide us a unique opportunity to study NSIs. NSIs is thought to be a very well anticipated phenomena. The effective Lagrangian for NSIs in model independent way is given in [1] and can be written as

$$L_{eff}^{NSI} = -2\sqrt{2}G_F \left[ \sum_{\alpha=\beta} \epsilon_{\alpha\beta}^{fP} (\bar{\nu}_\alpha \gamma_\mu L \nu_\beta) (\bar{f} \gamma^\mu P f) + \sum_{\alpha \neq \beta} \epsilon_{\alpha\beta}^{fP} (\bar{\nu}_\alpha \gamma_\mu L \nu_\beta) (\bar{f} \gamma^\mu P f) \right]$$

Here  $\epsilon_{\alpha\beta}^{fP}$  is the parameter for NSIs, which carries information about dynamics. NSIs are thought to be well-matched with the oscillation effects along with new features in neutrino searches [2][3][4][5][6][7][8]. It is believed that NSIs can affect neutrinos at production, propagation and detection level. Constraints

on NSIs parameter  $\epsilon_{\alpha\beta}^{fP}$  have been studied in References [9][10][12]. These are loop induced interactions in standard model (SM), consisting of charge as well as neutral vertices but NSIs will affect neutral vertices only [11]. From scattering in leptonic sectors ( $f$  is lepton), constraints are determined for first two generations  $\epsilon_{ll}^{fP}$  ( $l = e, \mu$ ) by tree level processes and could be limited at  $O(10^{-3})$  by future  $\sin^2 \theta_W$  experiments. For third generation ( $\tau$ ) decays which occur at loop level are studied. The limit of  $O(0.3)$  is expected for the third generation ( $\tau$ ) is KamLAND data [13] and solar neutrino data [14][15]. Although, the constraints on  $\epsilon_{\tau l}^{fP}$  are given by the precision experiments but they are bounded by  $O(10^{-2})$  [16]. It is pointed out in reference [23] that by using  $K^+ \rightarrow \pi^+ \bar{\nu} \nu$  the  $\epsilon_{\tau\tau}^{uL}$  constraints could be  $O(10^{-2})$ . Mostly  $f$  is lepton or quark from first generation ( $u$  or  $d$ ). If we take  $f$  from second generation of quark we have almost same constraints as for first generations,  $\epsilon_{\alpha\beta}^{cP} \approx \epsilon_{\alpha\beta}^{uP}$ . Similar thing happen to the other partner of  $c$ ,  $s$  quark and we can have  $\epsilon_{\alpha\beta}^{dP} \approx \epsilon_{\alpha\beta}^{sP}$ . We inspire from leptonic sector where we have  $\epsilon_{\alpha\beta}^{eP}$ ,  $\epsilon_{\alpha\beta}^{\mu P}$  and even  $\epsilon_{\alpha\beta}^{\tau P}$ . Although, no body is talking about these types of effects for the second generation simply due to the fact that the ordinary matter consist of only of first generation of quarks but we point out that just like second generation of leptons NSIs are also affected by second generation of quarks at the production of neutrinos from rare decays of mesons. These could be responsible for the flavor violating neutrino production.

We investigate  $K^+ \rightarrow \pi^+ \bar{\nu} \nu$ ,  $D_s^+ \rightarrow D^+ \bar{\nu} \nu$  and  $B_s^0 \rightarrow B^0 \bar{\nu} \nu$  processes for the this purpose. These processes will be very important tool for the search of possible new physics. Here we proceed as follows. We revise  $K^+ \rightarrow \pi^+ \bar{\nu} \nu$  in the SM as well in NSIs for  $c$  quark in the loop and then it is examined in NSIs with  $c$  in the loop.  $B_s^0 \rightarrow B^0 \bar{\nu} \nu$  is studied for the first time in NSIs with  $u$  quark. After this  $D_s^+ \rightarrow D^+ \bar{\nu} \nu$  and  $B_s^0 \rightarrow B^0 \bar{\nu} \nu$  are searched for NSIs with  $c$  quark. Just like these three other processes  $D^+ \rightarrow \pi^+ \bar{\nu} \nu$ ,  $D^0 \rightarrow \pi^0 \bar{\nu} \nu$  and  $D_s^+ \rightarrow K^+ \bar{\nu} \nu$  calculated with  $s$  quark instead of  $d$  quark. Then results and comparison is provided and conclusion is given at the end.

## 2 Experimental Status

It is expected that at the end of this decade we will be able to detect rare decays of meson involving neutrinos in the final state just like  $K^+ \rightarrow \pi^+ \bar{\nu} \nu$  [17]. But so far, it is the only semileptonic reaction involving two neutrinos in the final state who experimental value is known which is  $(1.7 \pm 1.1) \times 10^{-10}$  [18]. So by using this reaction we can point out exact region for the new physics.  $D_s^+ \rightarrow D^+ \bar{\nu} \nu$ ,  $B_s^0 \rightarrow B^0 \bar{\nu} \nu$ ,  $D^+ \rightarrow \pi^+ \bar{\nu} \nu$ ,  $D^0 \rightarrow \pi^0 \bar{\nu} \nu$  and  $D_s^+ \rightarrow K^+ \bar{\nu} \nu$  are yet to be detected. In super b-factories and in future super collider, we will have an opportunity to detect them in a clean environment.

### 3 Standard Model Calculations

These reactions are represented by the quark level process  $\bar{s} \longrightarrow \bar{d} \bar{\nu} \nu$  for which penguin diagram is

Figure

along with two box diagrams not shown here, and the effective hamiltonian is

$$H_{eff}^{SM} = \frac{G_F}{\sqrt{2}} \frac{\alpha_{em}}{2\pi \sin^2 \theta_W} \sum_{\alpha, \beta=e, \mu, \tau} (V_{cd}^* V_{cs} X_{NL}^l + V_{td}^* V_{ts} X(x_t)) \times (\bar{s}d)_{V-A} (\nu_\alpha \bar{\nu}_\beta)_{V-A}$$

where  $X_{NL}^l$  is the charm quark contribution.  $X(x_t)$  is representing top quark contribution. Such processes are dominated by short distance because long distance contribution are almost  $10^{-3}$  less than short distance. The up type quark in loop will increase the Branching ratios of these reactions. The causes of uncertainties for these types of reactions are  $CKM$  matrix elements and hadronic uncertainties but for  $K^+ \longrightarrow \pi^+ \bar{\nu} \nu$ ,  $D_s^+ \rightarrow D^+ \bar{\nu} \nu$  and  $B_s^0 \rightarrow B^0 \bar{\nu} \nu$  hadronic uncertainties can be eliminated by normalizing with tree level processes. So, these are theoretically clean processes in SM and due to loop they are very attractive for new physics.

SM Br of  $K^+ \longrightarrow \pi^+ \bar{\nu} \nu$  is given by

$$\frac{Br(K^+ \rightarrow \pi^+ \bar{\nu} \nu)}{Br(K^+ \rightarrow \pi^0 e^+ \nu)} = r_{K^+} \frac{\alpha_{em}^2}{|V_{us}|^2 2\pi^2 \sin^4 \theta_W} \sum_{\alpha, \beta=e, \mu, \tau} |V_{cd}^* V_{cs} X_{NL}^l + V_{td}^* V_{ts} X(x_t)|^2$$

We get the branching ratios (Br) for such reactions by normalizing with a tree level process which is linked with  $K^+ \longrightarrow \pi^+ \bar{\nu} \nu$  by isospin symmetry.

As  $\langle \pi^+ | (\bar{s}d)_{V-A} | K^+ \rangle = \sqrt{2} \langle \pi^0 | (\bar{s}u)_{V-A} | K^+ \rangle$

with  $r_{K^+} = 0.901$  is isospin effect given in [19] ;

Using  $V_{us} = 0.2252$ ;  $V_{ud} = 0.97425$ ;  $\theta_w = 28.7^\circ$ ;  $BR(K^+ \longrightarrow \pi^0 e^+ \nu_e) = 5.07 \times 10^{-2}$  [21] the SM Br of  $K^+ \longrightarrow \pi^+ \bar{\nu} \nu$  becomes  $(7.8 \pm 0.8) \times 10^{-11}$  [20]

The margin for NSIs in  $K^+ \longrightarrow \pi^+ \bar{\nu} \nu$  is equal to the difference of Br of theory and experiments which is equal to  $(0.92 \pm 1.18) \times 10^{-10}$  approximately equal  $10^{-10}$ . SM Br for  $D_s^+ \rightarrow D^+ \bar{\nu} \nu$  and  $B_s^0 \rightarrow B^0 \bar{\nu} \nu$  is calculated as

$$\frac{Br(D_s^+ \rightarrow D^+ \bar{\nu} \nu)}{Br(D_s^+ \rightarrow D^0 e^+ \nu)} = \frac{\alpha_{em}^2}{|V_{us}|^2 2\pi^2 \sin^4 \theta_W} \sum_{\alpha, \beta=e, \mu, \tau} |V_{cd}^* V_{cs} X_{NL}^l + V_{td}^* V_{ts} X(x_t)|^2$$

and

$$\frac{Br(B_s^0 \rightarrow B^0 \bar{\nu} \nu)}{Br(B_s^0 \rightarrow B^+ e^- \nu)} = \frac{\alpha_{em}^2}{|V_{us}|^2 2\pi^2 \sin^4 \theta_W} \sum_{\alpha, \beta=e, \mu, \tau} |V_{cd}^* V_{cs} X_{NL}^l + V_{td}^* V_{ts} X(x_t)|^2$$

Although for  $Br(D_s^+ \rightarrow D^0 e^+ \nu)$  and  $Br(B_s^0 \rightarrow B^+ e^- \nu)$  we do not have experimentally calculated values just like  $Br(K^+ \rightarrow \pi^0 e^+ \nu)$  but we have very

elegantly estimated values for BES-III given in [22] and we use them in our calculations. Here we are ignoring effects of isospin breaking  $D$  and  $B$  mesons.

Using  $Br(D_s^+ \rightarrow D^0 e^+ \nu) = 5 \times 10^{-6}$ ,  $Br(B_s^0 \rightarrow B^+ e^- \nu) = 4.46 \times 10^{-8}$  we get

$$\begin{aligned} Br(D_s^+ \rightarrow D^+ \bar{\nu} \nu)_{SM} &= 7.72 \times 10^{-15} \\ Br(B_s^0 \rightarrow B^0 \bar{\nu} \nu)_{SM} &= 6.86 \times 10^{-17} \end{aligned}$$

## 4 NSIs with u quark in the loop

The NSIs effective hamiltonian is given by

$$H_{eff}^{NSI} = \frac{G_F}{\sqrt{2}} (V_{us}^* V_{ud} \frac{\alpha_{em}}{4\pi \sin^2 \theta_W} \epsilon_{\alpha\beta}^{uL} \ln \frac{\Lambda}{m_w}) \times (\nu_\alpha \bar{\nu}_\beta)_{V-A} (\bar{s}d)$$

from which the NSIs Br

$$\begin{aligned} Br(K^+ \rightarrow \pi^+ \bar{\nu} \nu)_{NSI} &= r_{K^+} \frac{\alpha_{em}^2}{|V_{us}|^2 2\pi^2 \sin^4 \theta_W} |V_{us}^* V_{ud} \frac{1}{2} \epsilon_{\alpha\beta}^{uL} \ln \frac{\Lambda}{m_w}|^2 \times \\ &BR(K^+ \rightarrow \pi^0 e^+ \nu_e) \end{aligned}$$

This was calculated in [23] and the writers claimed that  $\epsilon_{\tau\tau}^{uL} \leq \frac{8.8 \times 10^{-3}}{\ln \frac{\Lambda}{m_W}}$ . With latest values  $\epsilon_{\tau\tau}^{uL} \leq \frac{6.7 \times 10^{-3}}{\ln \frac{\Lambda}{m_W}}$ . When we insert this value for our processes, we have

$$\begin{aligned} Br(B_s^0 \rightarrow B^0 \bar{\nu} \nu)_{NSI} &= \frac{\alpha_{em}^2}{|V_{us}|^2 2\pi^2 \sin^4 \theta_W} |V_{us}^* V_{ud} \frac{1}{2} \epsilon_{\alpha\beta}^{uL} \ln \frac{\Lambda}{m_w}|^2 \times \\ &Br(B_s^0 \rightarrow B^+ e^- \nu) \end{aligned}$$

Numerically we get

$$Br(B_s^0 \rightarrow B^0 \bar{\nu} \nu)_{NSI} = 2.17 \times 10^{-17}$$

The  $Br(D_s^+ \rightarrow D^+ \bar{\nu} \nu)_{NSI} = 2.70 \times 10^{-15}$  is given in [24]

## 5 NSIs with c quark in the loop

Now we take  $c$  quark in the loop instead of  $u$  quark

Fig 1.

The NSIs effective hamiltonian is given by

$$H_{eff}^{NSI} = \frac{G_F}{\sqrt{2}} (V_{cs}^* V_{cd} \frac{\alpha_{em}}{4\pi \sin^2 \theta_W} \epsilon_{\alpha\beta}^{cL} \ln \frac{\Lambda}{m_w}) \times (\nu_\alpha \bar{\nu}_\beta)_{V-A} (\bar{s}d)$$

Here, it is same as that of  $u$  quark in the loop and we are simply replacing  $c$  with  $u$ . The NSIs Br with  $c$  quark becomes

$$Br(K^+ \rightarrow \pi^+ \bar{\nu} \nu)_{NSI} = r_{K^+} \frac{\alpha_{em}^2}{|V_{us}|^2 2\pi^2 \sin^4 \theta_W} |V_{cs}^* V_{cd} \frac{1}{2} \epsilon_{\alpha\beta}^{cL} \ln \frac{\Lambda}{m_w}|^2 \times$$

$$BR(K^+ \rightarrow \pi^0 e^+ \nu_e)$$

Putting the values from [21] get calculate  $\epsilon_{\tau\tau}^{cL} \leq \frac{6.2 \times 10^{-3}}{\ln \frac{\Lambda}{m_W}}$ . When we insert this value for our processes, we have

$$Br(D_s^+ \rightarrow D^+ \bar{\nu} \nu)_{NSI} = \frac{\alpha_{em}^2}{|V_{us}|^2 2\pi^2 \sin^4 \theta_W} |V_{cs}^* V_{cd} \frac{1}{2} \epsilon_{\alpha\beta}^{cL} \ln \frac{\Lambda}{m_w}|^2 \times$$

$$Br(D_s^+ \rightarrow D^0 e^+ \nu)$$

$$Br(B_s^0 \rightarrow B^0 \bar{\nu} \nu)_{NSI} = \frac{\alpha_{em}^2}{|V_{us}|^2 2\pi^2 \sin^4 \theta_W} |V_{cs}^* V_{cd} \frac{1}{2} \epsilon_{\alpha\beta}^{cL} \ln \frac{\Lambda}{m_w}|^2 \times$$

$$Br(B_s^0 \rightarrow B^+ e^- \nu)$$

$$Br(D_s^+ \rightarrow D^+ \bar{\nu} \nu)_{NSI} = 2.57 \times 10^{-15}$$

$$Br(B_s^0 \rightarrow B^0 \bar{\nu} \nu)_{NSI} = 2.0 \times 10^{-17}$$

## 6 Rare Decays of D in The Standard Model

SM Hamiltonian for short distance contribution of  $c \rightarrow u \nu \bar{\nu}$  is given by

$$H_{eff}^{SM} = \frac{G_F}{\sqrt{2}} \frac{\alpha_{em}}{2\pi \sin^2 \theta_W} \sum_{\alpha, \beta=e, \mu, \tau} [V_{cs}^* V_{us} X(x_s) + V_{cb}^* V_{ub} X(x_b)] \times (\bar{u}c)_{V-A} (\nu_\alpha \bar{\nu}_\beta)_{V-A}$$

but for  $D_s^+ \rightarrow K^+ \nu_\alpha \bar{\nu}_\beta$ ,  $D^+ \rightarrow \pi^+ \nu_\alpha \bar{\nu}_\beta$  and  $D^0 \rightarrow \pi^0 \nu_\alpha \bar{\nu}_\beta$  the dominant contribution comes from long distance. It is free from QCD complications because they can be normalized with tree level process. Their SM contribution is given in table 2.

## 7 NSIs in $D_s^+ \rightarrow K^+ \nu_\alpha \bar{\nu}_\beta$ , $D^+ \rightarrow \pi^+ \nu_\alpha \bar{\nu}_\beta$ and $D^0 \rightarrow \pi^0 \nu_\alpha \bar{\nu}_\beta$

The quark level process  $c \rightarrow u \nu_\alpha \bar{\nu}_\beta$  is representing all above processes. For  $D^+ \rightarrow \pi^+ \nu_\alpha \bar{\nu}_\beta$ , NSIs with  $u$  quark in the loop it is calculated in [23]

$$Br(D^+ \rightarrow \pi^+ \nu_\alpha \bar{\nu}_\beta)_{NSI} = |V_{ud}^* \frac{\alpha_{em}}{4\pi \sin^2 \theta_W} \epsilon_{\alpha\beta}^{dL} \ln \frac{\Lambda}{m_W}|^2 BR(D^+ \rightarrow \pi^0 e^+ \nu_e)$$

$Br(D^+ \rightarrow \pi^+ \nu_\alpha \bar{\nu}_\beta)_{NSI} = 3.20 \times 10^{-8} |\epsilon_{\alpha\beta}^{dL} \ln \frac{\Lambda}{m_W}|^2$  and it is mentioned that as  $\alpha$  and  $\beta$  could represent any lepton, we take  $\epsilon_{\tau\tau}^{dL} \sim 1$ ,  $\epsilon_{ll'}^{dL} \langle 1$  for  $l = l' \neq \tau$ . Here  $\ln \frac{\Lambda}{m_W} \sim 1$ .

If we take  $s$  quark in the loop instead of  $d$  quark, then it is given by

Figure 2.

$$H_{c \rightarrow u\nu_\alpha \bar{\nu}_\beta}^{NSI} = \frac{G_F}{\sqrt{2}} \left( \frac{\alpha_{em}}{4\pi \sin^2 \theta_W} V_{cs} V_{us}^* \epsilon_{\alpha\beta}^{sL} \ln \frac{\Lambda}{m_W} \right) (\bar{\nu}_\alpha \nu_\beta)_{V-A} (\bar{c}u)_{V-A}$$

and  $Br$  becomes

$$Br(D^+ \rightarrow \pi^+ \nu_\alpha \bar{\nu}_\beta)_{NSI} = \left| \frac{V_{us}^* V_{cs}}{V_{cd}} \times \frac{\alpha_{em}}{4\pi \sin^2 \theta_W} \epsilon_{\alpha\beta}^{sL} \ln \frac{\Lambda}{m_W} \right|^2 Br(D^+ \rightarrow \pi^0 e^+ \nu_e)$$

$Br(D^+ \rightarrow \pi^+ \nu_\alpha \bar{\nu}_\beta)_{NSI} = 3.25 \times 10^{-8} |\epsilon_{\alpha\beta}^{sL} \ln \frac{\Lambda}{m_W}|^2$  and it is mentioned that as  $\alpha$  and  $\beta$  could represent any lepton, we take  $\epsilon_{\tau\tau}^{sL} \sim 1$ ,  $\epsilon_{ll'}^{sL} \langle 1$  for  $l = l' \neq \tau$ . Here  $\ln \frac{\Lambda}{m_W} \sim 1$ . We further see that same is applicable to two other processes  $D_s^+ \rightarrow K^+ \nu_\alpha \bar{\nu}_\beta$  and  $D^0 \rightarrow \pi^0 \nu_\alpha \bar{\nu}_\beta$ .

$$Br(D_s^+ \rightarrow K^+ \nu_\alpha \bar{\nu}_\beta)_{NSI} = \left| \frac{V_{us}^* V_{cs}}{V_{cd}} \frac{\alpha_{em}}{4\pi \sin^2 \theta_W} \epsilon_{\alpha\beta}^{sL} \ln \frac{\Lambda}{m_W} \right|^2 Br(D_s^+ \rightarrow K^0 e^+ \nu_e)$$

$$Br(D^0 \rightarrow \pi^0 \nu_\alpha \bar{\nu}_\beta)_{NSI} = \left| \frac{V_{us}^* V_{cs}}{V_{cd}} \frac{\alpha_{em}}{4\pi \sin^2 \theta_W} \epsilon_{\alpha\beta}^{sL} \ln \frac{\Lambda}{m_W} \right|^2 Br(\bar{D}^0 \rightarrow \pi^- e^+ \nu_e)$$

Using PDG 2012 [21] Values  $Br(D_s^+ \rightarrow K^0 e^+ \nu_e) = (3.7 \pm 1) \times 10^{-3}$ ,  $V_{ud} = 0.97425 \pm 0.00022$ ,  $\alpha_{em} = \frac{1}{137}$ , we get

$$Br(D_s^+ \rightarrow K^+ \nu_\alpha \bar{\nu}_\beta)_{NSI} = 2.28 \times 10^{-8} (\epsilon_{\alpha\beta}^{sL})^2 \left| \ln \frac{\Lambda}{m_W} \right|^2$$

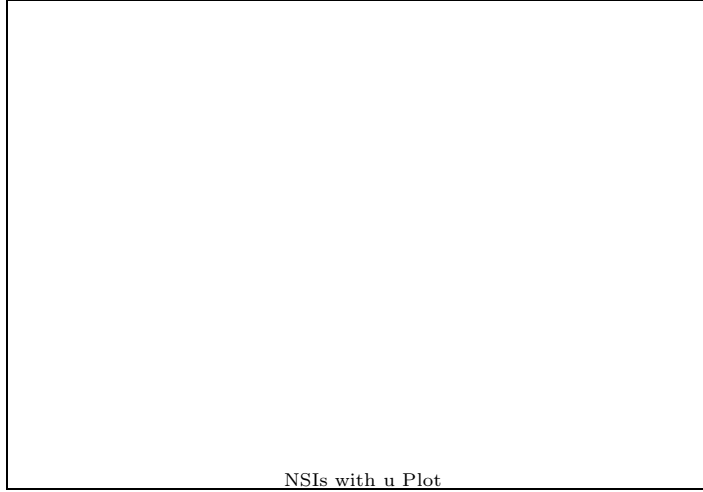
For  $\epsilon_{\tau\tau}^{sL} \sim 1$  and  $\ln \frac{\Lambda}{m_W} \sim 1$ , we get  $Br(D_s^+ \rightarrow K^+ \nu_\alpha \bar{\nu}_\beta)_{NSI} = 0.14 \times 10^{-8}$ .

Similarly for  $Br(\bar{D}^0 \rightarrow \pi^- e^+ \nu_e) = 2.89 \times 10^{-3}$  we have

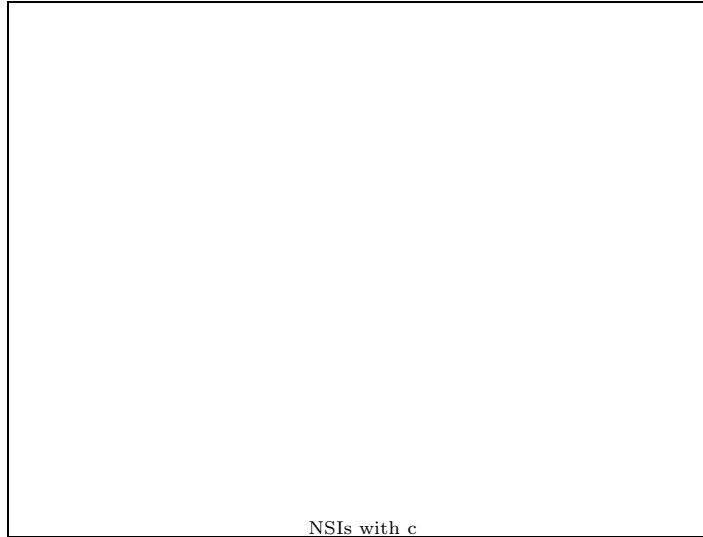
$$Br(D^0 \rightarrow \pi^0 \nu_\alpha \bar{\nu}_\beta)_{NSI} = 3.25 \times 10^{-8} (\epsilon_{\alpha\beta}^{sL})^2 \left| \ln \frac{\Lambda}{m_W} \right|^2$$

$10^{-8}$  will be the reach of BES-III, so it is hoped that we might observe these decays there. If not, even than useful limits for new physics can be suggested. NSIs with  $d$  quark are discussed for  $D_s^+ \rightarrow K^+ \nu_\alpha \bar{\nu}_\beta$ , and  $D^0 \rightarrow \pi^0 \nu_\alpha \bar{\nu}_\beta$  in [24]. Both values are summarized in table two for comparison.

## 8 Results and Summary



NSIs with u Plot



NSIs with c

Contour as a function of new physics  
scale  $\Lambda$  and  $\epsilon_{\tau\tau}^{dL}$

Contour as a function of new physics  
scale  $\Lambda$  and  $\epsilon_{\tau\tau}^{sL}$

It is evident from the plots above and table 1 that  $\epsilon_{\alpha\beta}^{cL} \approx \epsilon_{\alpha\beta}^{uL} \leq 10^{-2}$ . As we have both experimental and theoretical values for  $K^+$  decay so we can specify exact region for new physics. But for other two reactions only expected contribution from NSIs can be given. The  $D_s^+ \rightarrow D^+ \bar{\nu} \nu$  and  $B_s^0 \rightarrow B^0 \bar{\nu} \nu$  are decays of B and charm mesons respectively but the quark decay processes is similar to the  $K$  meson decay. These are very heavy mesons and decaying into again heavy mesons so there is a lot of energy required for their observation. These are sensitive to  $c$  quark just like  $u$  quark. We know that we have second and even third generation constraints on free parameter of NSIs for charge leptons, like  $\epsilon_{\alpha\beta}^e, \epsilon_{\alpha\beta}^\mu$  and  $\epsilon_{\alpha\beta}^\tau$  but we have only  $\epsilon_{\alpha\beta}^{uL}$  and  $\epsilon_{\alpha\beta}^{dL}$ . From the other three reactions  $D_s^+ \rightarrow K^+ \nu_\alpha \bar{\nu}_\beta$ ,  $D^+ \rightarrow \pi^+ \nu_\alpha \bar{\nu}_\beta$  and  $D^0 \rightarrow \pi^0 \nu_\alpha \bar{\nu}_\beta$  we find  $\epsilon_{\alpha\beta}^{sL}$ , and we come to know that  $\epsilon_{\alpha\beta}^{dL} = \epsilon_{\alpha\beta}^{sL}$ . So, both generation of quarks  $\begin{pmatrix} u \\ d \end{pmatrix}$  and  $\begin{pmatrix} c \\ s \end{pmatrix}$  could affect NSIs of the rare decays of mesons.



Reaction	Theoretical Br	Experimental Br	NSIs for $u$	NSIs for $c$
$K^+ \rightarrow \pi^+ \bar{\nu} \nu$ $(u\bar{s}) \rightarrow (u\bar{d}) \bar{\nu} \nu$	$(7.8 \pm 0.8) \times 10^{-11}$ [20]	$(1.7 \pm 1.1) \times 10^{-10}$ [18]	$2.46 \times 10^{-11}$	$2.42 \times 10^{-11}$
$D_s^+ \rightarrow D^+ \bar{\nu} \nu$ $(c\bar{s}) \rightarrow (c\bar{d}) \bar{\nu} \nu$	$7.69 \times 10^{-15}$	not known	$2.70 \times 10^{-15}$	$2.57 \times 10^{-15}$
$B_s^0 \rightarrow B^0 \bar{\nu} \nu$ $(s\bar{b}) \rightarrow (\bar{b}d) \bar{\nu} \nu$	$6.86 \times 10^{-17}$	not known	$2.17 \times 10^{-17}$	$2.0 \times 10^{-17}$

Table 1.

$$\epsilon_{\tau\tau}^{uL} \sim O(10^{-2}) \quad \epsilon_{\tau\tau}^{cL} \sim O(10^{-2})$$

Reaction	SM Br			NSIs for $d$	NSIs for $s$
$D^+ \rightarrow \pi^+ \nu_\alpha \bar{\nu}_\beta$	Long Distance	$< 8 \times 10^{-16}$	[25]	$3.21 \times 10^{-8}$	$3.25 \times 10^{-8}$
	Short Distance	$3.9 \times 10^{-16}$			
$D_s^+ \rightarrow K^+ \nu_\alpha \bar{\nu}_\beta$	Long Distance	$< 4 \times 10^{-16}$	[26]	$2.23 \times 10^{-8}$	$2.28 \times 10^{-8}$
	Short Distance	$1.5 \times 10^{-16}$			
$D^0 \rightarrow \pi^0 \nu_\alpha \bar{\nu}_\beta$	Long Distance	$< 6 \times 10^{-16}$	[25]	$3.21 \times 10^{-8}$	$3.25 \times 10^{-8}$
	Short Distance	$4.9 \times 10^{-16}$			

Table 2.

$$\epsilon_{\tau\tau}^{dL} \sim 1 \quad \epsilon_{\tau\tau}^{sL} \sim 1 \quad \text{and} \quad \epsilon_{ll'}^{dL} \langle 1 \quad \epsilon_{ll'}^{sL} \langle 1 \quad \text{for } l = l' \neq \tau$$

## 9 Conclusion

We have calculated NSIs Br of  $B_s^0 \rightarrow B^0 \bar{\nu} \nu$  in NSIs and from this constraints for  $\epsilon_{\tau\tau}^{uL}$  are  $O(10^{-2})$ . Further, we have observed that from  $K^+ \rightarrow \pi^+ \bar{\nu} \nu$ ,  $D_s^+ \rightarrow D^+ \bar{\nu} \nu$  and  $B_s^0 \rightarrow B^0 \bar{\nu} \nu$  constraints on  $\epsilon_{\tau\tau}^{cL}$  are also  $O(10^{-2})$  just like  $\epsilon_{\tau\tau}^{uL}$ . We get Br of these decays in NSIs with  $c$  quark in the loop, which are exactly same as that for  $u$  quark in the loop. These provide us a proof of  $c$  quark induced processes for NSIs which could affect the rare decay processes. Just like these,  $D^+ \rightarrow \pi^+ \bar{\nu} \nu$ ,  $D^0 \rightarrow \pi^0 \bar{\nu} \nu$  and  $D_s^+ \rightarrow K^+ \bar{\nu} \nu$  processes are giving  $\epsilon_{\tau\tau}^{sL} \sim 1$  and  $\epsilon_{ll'}^{sL} \langle 1$  exactly on equal footing with  $d$  quark. These could also affect the rare decays of charm mesons. As a result it could safely be concluded that second generation of quark is affecting NSIs just like first generation of quark and in NSIs effects of second generation should be included, especially at production level.

## References

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